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Landscape-scale and Macrohabitat-scale Variation in Growth and Survival of Young June Sucker (Chasmistes liorus) in Utah Lake

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ABSTRACT

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The spatial scales at which ecological phenomena are viewed constrain the results of interactions between species and their environments. In lake ecosystems, important dynamics have been identified at the landscape scale and the macrohabitat scale. To determine if landscape-scale effects and macrohabitat-scale effects are important in survival and growth of young June suckers, we compared variation among sites in Utah Lake. Large semi-permeable cages were used to house June suckers *in situ* at five sites representing landscape-scale variation and two sites representing macrohabitat-scale variation in Utah Lake. We compared survival and growth among sites and related it to resource availability (zooplankton abundances), temperature, and disturbance regime to determine if these were possible drivers of variation. Provo Bay had the highest mean survival and high survival in all four cages. Growth differed among sites: Provo Bay and the northwest site had the highest and lowest mean growth rates, respectively. Survival was higher in vegetated water than open water, whereas growth was significantly higher in open water. Zooplankton densities were highest in Provo Bay and the open water habitat, suggesting a positive relationship between food abundance and growth. Temperature patterns were not consistent with differences in growth among sites. Disturbance was greater in the open lake, which may partly explain the higher survival rates in Provo Bay.

Keywords: June sucker, *Chasmistes liorus*, Utah Lake, landscape, macrohabitat, scale

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INTRODUCTION

Ecological interactions are scale-dependent (Werner 1998; Wiens 1989; Wiens et al. 1986). Predictable patterns may only occur within discrete ranges of scale, called domains (Wiens 1989). In freshwater systems, distinctive domains have been identified at the landscape scale (Leavitt et al. 2006; Zambrano et al. 2010) and the macrohabitat scale (Joniak et al. 2007). The landscape scale has been defined as encompassing "hectares to hundreds of square kilometers" (Turner 1989). In lake systems, sites at different areas across this scale may vary in substrate, geology, wave energy, tributary inflows, and nutrient input levels (e.g. Leavitt et al. 2006). The macrohabitat scale is nested within the larger landscape scale. Two distinct macrohabitat types exist within lakes: vegetated and open water. These two major types are known to differ in light penetration, structural complexity, and water chemistry (Joniak et al. (Joniak et al. 2007).

June sucker *Chasmistes liorus* is an endangered fish endemic to Utah Lake, Utah, USA and associated tributaries (U. S. Fish and Wildlife Service 1999; USOFR 1986). June sucker is zooplanktivorous. Young June suckers feed primarily on *Brachionus* sp. rotifers and cyclopoid copepods, specifically, *Microcyclops rubellus* (Kreitzer et al. *in press*). June sucker is declining in large part because of a lack of recruitment of juveniles to the breeding population (Ellsworth et al. *in press;* U. S. Fish and Wildlife Service 1999). Thousands of age-1 suckers raised in the hatchery are stocked in Utah Lake each year to augment the population. However, to create a self-sustaining population of June sucker, it is important to understand factors that influence growth and survival of young June sucker at various scales in Utah Lake.

Utah Lake is a large, shallow, eutrophic lake at the eastern edge of the Great Basin physiographic province (Fuhriman et al. 1981). Utah Lake exhibits habitat variation at both the landscape and macrohabitat scale. At the landscape scale, there are differences in wind-induced wave action, underlying geological structure, and the effects of inflowing tributaries. Provo Bay, a large, shallow extension of the lake, has a reduced fetch and wide emergent macrophyte margin which contributes to decreased wave action compared to the main body of the lake (hereafter open lake). At the macrohabitat scale, phragmites *Phragmites australis*, bulrushes *Scirpus acutus*, and cattails *Typha latifolia* provide complex habitat compared to the open water habitat. Habitat differences can contribute to differences in survival and growth rates among locations (Jeffres et al. 2008). To achieve recovery of June sucker it is important to understand how habitat variation in Utah Lake contributes to differential growth and survival of young June sucker.

We tested for landscape-scale and macrohabitat-scale variation in growth and survival of young June sucker in Utah Lake. At the landscape scale we also measured patterns of variation in three potential determinants of growth and survival of young June sucker - zooplankton abundance, temperature, and disturbance regime. At the macrohabitat scale, we compared growth and survival with zooplankton abundance.

METHODS

Landscape-scale Study

The landscape-scale study was conducted in Utah Lake at sites representative of the range of landscape-scale variation found in the lake, specifically Provo Bay (PB), northeast main lake (NE), northwest main lake (NW), southeast main lake (SE), and southwest main lake (SW; Figure 1). The Provo Bay site was located in open water in the north-central part of the bay (40˚ 11. 686’, 111˚ 41.909’) with a mean water depth of 1.16 m and a 10-40 cm layer of fine sediment. Wave action was relatively mild at this site. The northwest site was located near Saratoga Springs City (40˚ 18.940’, 111˚ 53.160’) with a mean depth of 2.11 m and a substrate comprised of rock and silt. The northeast site was located near Lindon Beach (40˚ 18.718’, 111˚ 45.937’) with a mean depth of 1.29 m and a sandy substrate. The southwest site was located on the eastern shore of Goshen Bay (40˚ 07.134’, 111˚ 50.837’) with a mean depth of 1.73 m and a rocky substrate. The southeast site was located southwest of the Spanish Fork River mouth in Spanish Fork Bay (40˚ 09.760’, 111˚ 45.135’) with a mean depth of 1.77 m and a sandy substrate.

June suckers were kept in four replicate floating cages at each site. The cages were 3 x 2 x 1 m PVC pipe (2.54 cm diameter) frames covered with vinyl-coated polyester screening (1.5 mm) on the vertical sides and bottom, representing a slightly smaller version of a floating cage used in a previous study (Billman and Belk 2009). The polyester screening was fine enough to prevent larval fish escape while still allowing zooplankton access into the cage (Gonzalez 2004). The top of the cage was covered with 4 cm open-mesh netting to deter predation by birds and mammals. The closed-cell foam float-tubes were attached to the cage below the top to provide flotation. An 18 kg concrete anchor was secured by steel chain to one corner of each cage. A yellow buoy (51 cm diameter) was attached to each cage to increase cage visibility to boaters. The cages were close enough to each other to facilitate maintenance but far enough apart to reduce wind- or wave-induced collisions. Jim-Buoy® number 9000 lights were installed on one cage at each site to flash at night to alert boaters.

The cages were placed at their respective sites on July 8-9, 2008. Larval June suckers were brought from the Fisheries Experimental Station hatchery in Logan, UT and stocked into the cages on July 21-23. To minimize stress in transit, suckers were placed at low density in aerated coolers. Suckers were stocked into the cages randomly over three days. Cages were observed often to detect damage. Cages were moved out to open water if blown ashore. Extra float tubes were added after the experiment began to increase cage buoyancy.

Each cage initially received 600 larval June sucker. The larvae were from a cohort of hatchery fish that were six weeks old. Larvae of this age have been used to grow out June sucker in Utah Lake (Billman and Belk 2009; Kreitzer et al. *in press*). At the end of the experiment, August 25-27, the fish were removed from the cages and counted to calculate survival for each cage. Cages which were significantly damaged during the study were removed from the survival analysis. Comparisons were made among sites using ANOVA with the Tukey-Kramer procedure for post-hoc means comparison in NCSS® (Hintze 2008).

To determine growth, standardized digital photographs were taken of the fish and measured by using the computer program TpsDig2® (Rohlf 2008). Fish were photographed in groups of about 25 individuals in a shallow tray with a ruler for scale. A subsample of at least 50 fish from each cage was measured to calculate mean final standard length. In cages with fewer than 50 surviving individuals, all fish visible in the photos were measured. The initial mean standard length, taken when fish were stocked, (15.13 mm, SE=0.18 mm, calculated from a subsample) was subtracted from the mean final standard length from each cage to determine growth during the experiment.

Macrohabitat-scale Study

The macrohabitat-scale experiment was conducted in the eastern part of Provo Bay, east of the landscape-scale Provo Bay site. The open water site was located near the eastern limit of open water in Provo Bay (40˚ 11.454’, 111˚ 40.109’). Mean depth was 0.66 m. The vegetated site was located in the aquatic macrophyte beds 0.21 km east of the open water site (40˚ 11.385’, 111˚ 39.994’). Mean depth was 0.52 m.

For this experiment, June suckers were kept in four PVC cages (0.5 x 1.0 x 1.0 m) that were fixed to the substrate at each site. These cages were similar to those used in a previous study, with screening covering all vertical sides and the bottom (Kreitzer et al. *in press*). Each cage received 25 larval suckers from the Fisheries Experimental Station hatchery. All fish were counted and photographed at the beginning (23 Jul) and the end (19 Sep) of the eight-week study to calculate survival and growth.

Resource Availability

Zooplankton samples were collected at each of the five landscape-scale sites and at both macrohabitat-scale sites. The samples were collected near, but not within cages. Each site was sampled three times; on weeks one, three, and five of the landscape-scale study and weeks one, three, and six of the macrohabitat-scale study. Three replicate samples were collected at each time period, resulting in a total of nine samples per site. Zooplankton were collected by lowering a 20 cm diameter plankton net to the bottom of the lake, allowing the water to settle, moving the net 30 cm to the side and then pulling it to the surface (Kreitzer et al. *in press*).

Samples were stored in 70% ethyl alcohol. For counting, the samples were strained through 63 μm mesh and then rinsed with water into a beaker to a set volume. To calculate the number of subsamples needed to accurately estimate abundance, we followed methods outlined in Elliott (1977). A minimum of two subsamples (2 mL each) was counted for each sample. We compared total zooplankton abundance among sites, and abundances of two specific taxa (*Brachionus* sp. rotifers and cyclopoid copepods) that are known to be important in the diet of June suckers at this age (Kreitzer et al. *in press*).

Temperature

Temperature data was collected in 2007 at several sites across the lake (Table 1; Spall et al. 2009). Relative patterns of temperature across the lake are assumed to be consistent across years. We calculated the number of degree days as the degrees above 10 ° C summed over the period covered by the experimental studies. The estimated average growth per degree day is 0.04 mm.

RESULTS

Landscape-scale Study

Mean survival within undamaged cages ranged from 78% in Provo Bay to 63% at the northeast site (Figure 2). Survival of June sucker did not differ significantly among sites ($F_{4, 10}$ = 1.27, p = 0.344). Mean growth ranged from 23.5 mm in Provo Bay to 18.2 mm at the northwest site. Growth differed significantly among sites ($F_{4, 14}$ = 3.58, p = 0.033). Fish were 16% longer in Provo Bay compared to the northwest site (Figure 3).

Zooplankton densities differed among sites on week one ($F_{4, 9}$ = 36.16, p < 0.001), week three ($F_{4, 10}$ = 16.56, p < 0.001), and week five ($F_{4, 10}$ = 18.06, p < 0.001). On weeks one and five, the Provo Bay site had significantly higher zooplankton density than the other sites (Post-hoc Tukey-Kramer test; Figure 4). At week three, Provo Bay and the northeast site had significantly higher densities than the other sites (Post-hoc Tukey-Kramer test; Figure 4). By week five, Provo Bay had significantly greater zooplankton densities than all other sites (Post-hoc Tukey-Kramer Test; Figure 4).

Abundance of *Brachionus* sp. rotifers differed among sites at week one ($F_{4, 9}$ = 124.33, p < 0.001), week three ($F_{4, 10}$ = 38.31, p < 0.001), and week five ($F_{4, 10}$ = 8.16, p = 0.003). *Brachionus* sp. was significantly more abundant at Provo Bay at weeks one, three, and five (Post-hoc Tukey-Kramer tests; Figure 4).

Abundance of cyclopoid copepods differed among sites at week one ($F_{4, 10}$ = 8.55, p = 0.003), week three ($F_{4, 10}$ = 27.56, p < 0.001), and week five ($F_{4, 10}$ = 43.73, p < 0.001). On weeks one and three, Provo Bay and the northeast site had higher densities of cyclopoid copepods than the other sites (Post-hoc Tukey-Kramer tests; Figure 4). At week five, cyclopoid copepod densities were significantly higher at Provo Bay than all other sites (Post-hoc Tukey-Kramer test; Figure 4).

Temperature differences across the lake were small (Table 1). Harsh conditions at the open lake sites resulted in cage damage at the northwest site (one cage), northeast site (two cages), and southwest site (two cages). Minor structural damage occurred at the southeast site, but it was non-compromising. None of the Provo Bay cages were damaged.

Macrohabitat–scale Study

Survival differed marginally between open (0.7 = survival) and vegetated (0.9) sites, (two-tailed *t*-test; $p = 0.051$). Growth was significantly greater in the open site (39.3 mm) compared to the vegetated site (31.9 mm; two-tailed *t*-test; $p = 0.002$).

Total zooplankton abundance did not differ between sites at weeks one (two-tailed *t*-test; $p = 0.539$) or three (two-tailed *t*-test; $p = 0.189$). However, the open water site had significantly higher numbers of zooplankton at week six (two-tailed *t*-test, $p = 0.031$; Figure 5). *Brachionus* sp. rotifer density did not differ between sites at weeks 1 (two-tailed *t*-test; $p = 0.231$) or three (two-tailed *t*-test; $p = 0.332$), but *Brachionus* sp. density was higher at the open water site at week six (two-tailed *t*-test; $p = 0.033$; Figure 5). Cyclopoid copepod density did not differ between sites at weeks one (two-tailed *t*-test; $p = 0.607$), three (two-tailed *t*-test; $p = 0.097$), or six (two-tailed *t*-test; $p = 0.159$).

DISCUSSION

Landscape-scale survival of young June sucker showed wide variation within sites while growth showed relatively low levels of variation within sites. Macrohabitat-scale survival and growth both showed low levels of variation, but the two variables did not covary. The differences in variability (at the landscape scale) and the lack of covariation (at the macrohabitat scale) suggest that survival and growth were decoupled in young June sucker. In other species, survival and growth covary (Friedland et al. 2000; Islam et al. 2010). In this study, survival and growth might have been responding to different scales of variation. Growth was the better determinant of higher habitat quality at the landscape scale. Determining the suitability of a given site requires an understanding of the effects of scale (Hopkins and Burr 2009).

Zooplankton abundance was related to the growth rates of June suckers at both the landscape scale and the macrohabitat scale. Landscape-scale sites with the highest density of zooplankton (week 3) coincided with the highest growth rates. The number of cyclopoid copepods in particular related clearly to growth rates (at weeks 1, 3, and 5; Figures 3 and 4). In the macrohabitat-scale study, higher zooplankton abundance at the open site was related to increased growth at that site. The temperature pattern does not explain the difference in growth. The six degree day difference observed is much less than the predicted 97.5 degree day difference required to create the observed 3.97 mm difference in size and it is in the opposite direction.

Resource availability is a predictor of growth rates in many systems (Gimenez 2010; Yuan et al. 2010). Apparent high mortality of larvae and juvenile June suckers in the native environment may be due at least in part to a decline in available food resources. Channelization of the Provo River mouth has likely decreased the number and size of zooplankton-rich slackwater habitats which would have been used during the larval drift to Utah Lake (Ellsworth et al. *in press;* Ning et al. 2010). Declining growth rates due to this decline in food are likely to lead to decreasing survival rates over time in species such as the June sucker, which are assumed to have a higher likelihood of survival with increased size due to increased ability to avoid predation and starvation (Sogard 1997). Larger juveniles are expected to have increased winter survival in the temperate zone (Conover 1992; Sogard 1997).

The distinctive differences between open and vegetated water in the macrohabitat-scale study support the classic tradeoff model, with June suckers showing higher growth rates in the open water but higher survival in the vegetation (Gilliam and Fraser 1987; Werner and Hall 1988). Increased growth in the open water is related to the increased abundance of zooplankton (Figures 3 and 5). The traditional explanation for reduced survival in open water habitats is increased predation; however, this was not a factor in our study due to predator exclusion. Thus, the reason behind reduced survival in open water in this study is unclear. Further research is needed to determine the causes, but it is plausible to consider that increased stress in the open water led to decreased survival.

Theory suggests larvae ought to prefer vegetation to avoid predation while larger juveniles should venture more often into the open water to enhance their growth rates. Vegetation has been shown to provide a refuge from predation for fish, including June suckers, (Kovalenko et al. 2010; Thomas and Crowl 1997). To maximize growth and survival, however, we would expect June suckers to spend time in both open and vegetated habitats, or, perhaps, to inhabit habitats with an intermediate level of vegetation (Ferrer-Montano and Dibble 2002).

TABLES AND FIGURES

Table 1. Synopsis of temperature data recorded in Utah Lake in early summer (Jun 21-Jul 18, 2007) and late summer (Jul 20-Aug 28, 2007). Data collected by Robert Spall (Spall et al. 2009).

Site	Latitude	Longitude	Temperature Record Dates	Early Summer Accumulated Degree Days	Late Summer Accumulated Degree Days	Distance from Nearest Shore
Provo Bay	40.18269	-111.698	May 24-Aug 28, 2007	396.09	571.88	657m
Knolls	40.14869	-111.865	May 24-Aug 28, 2007	411.56	595.89	2871m
Bird Island	40.17427	-111.809	Jun 21-Aug 28, 2007	411.94	593.19	3084m
South American Fork	40.31912	-111.813	Jun 21-Aug 28, 2007	429.69	610.03	2485m
West Saratoga Springs	40.30962	-111.881	May 23-July 18, 2007	392.52	-	255m
Saratoga Springs	40.29803	-111.819	May 24-Jul 18, 2007	408.59	-	4326m
South Springs	40.20968	-111.807	Jun 21-Jul 18, 2007	405.17	-	5504m
Goshen Bay	40.09097	-111.874	Jul 20-Aug 28, 2007	-	577.71	913m

Figure 1.

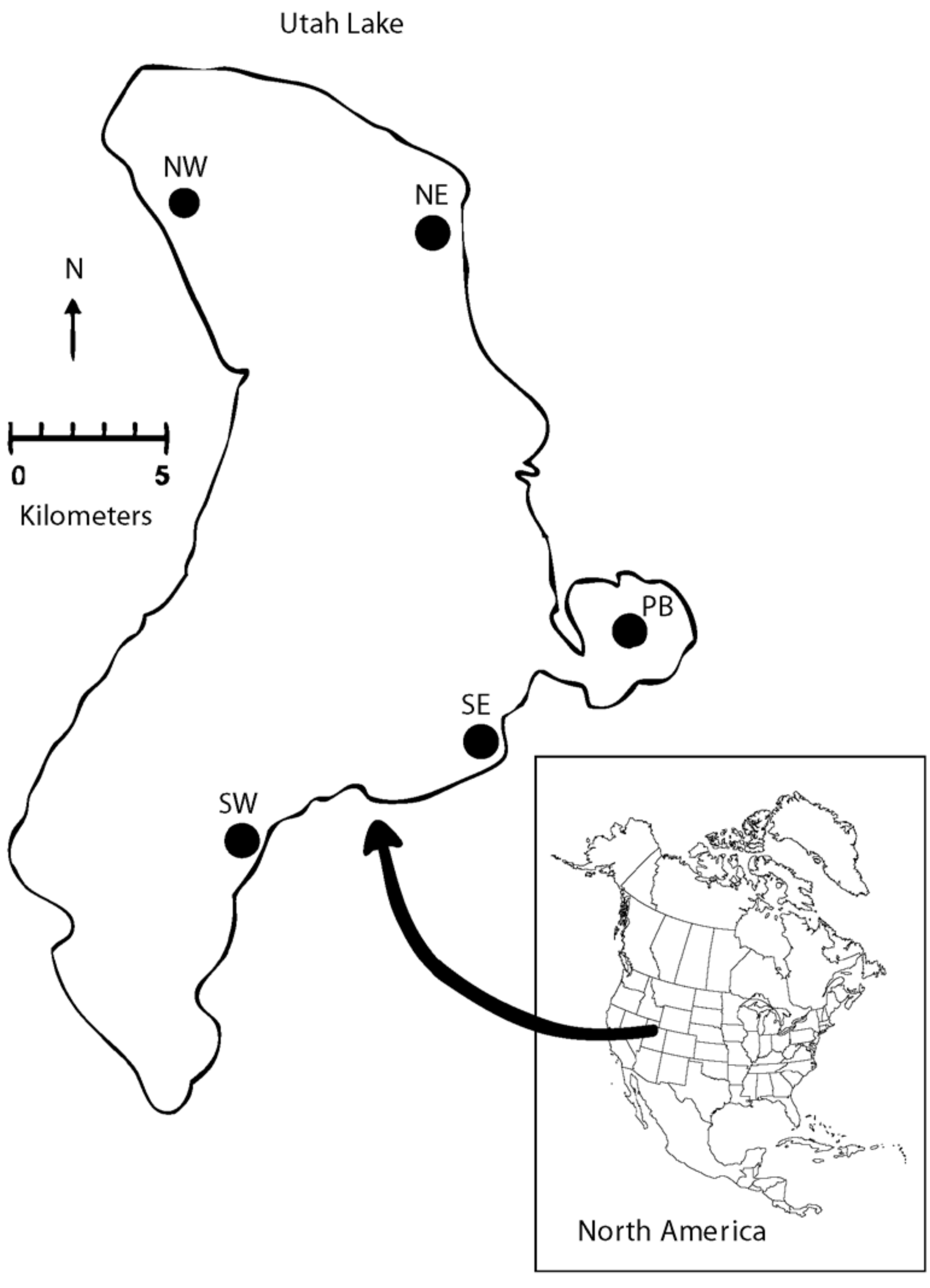


Figure 2.

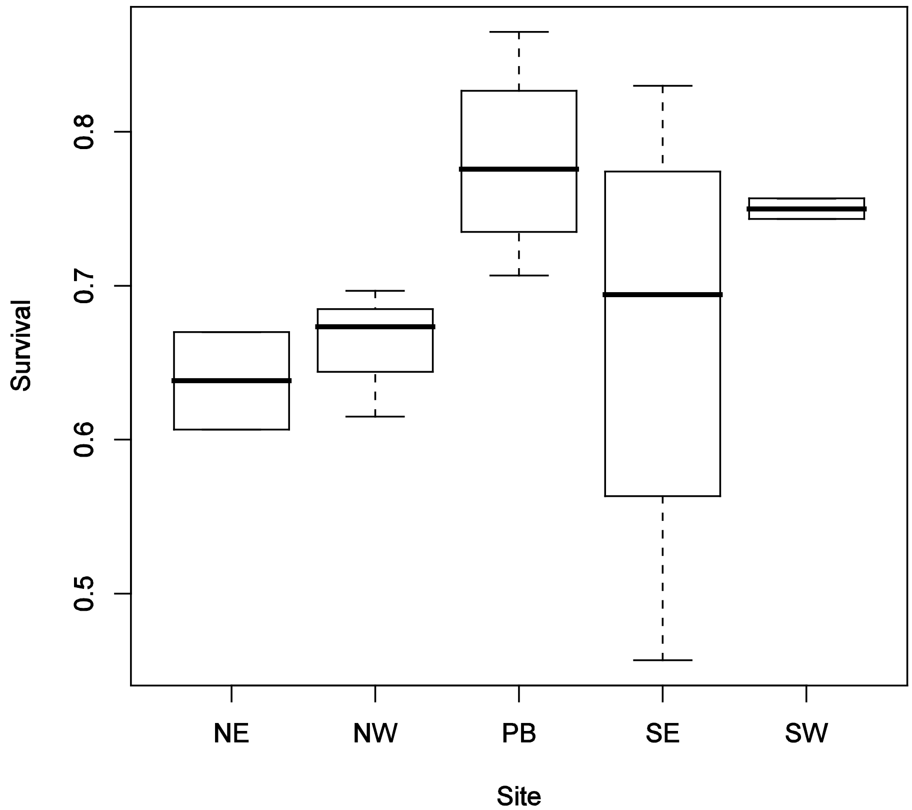


Figure 3.

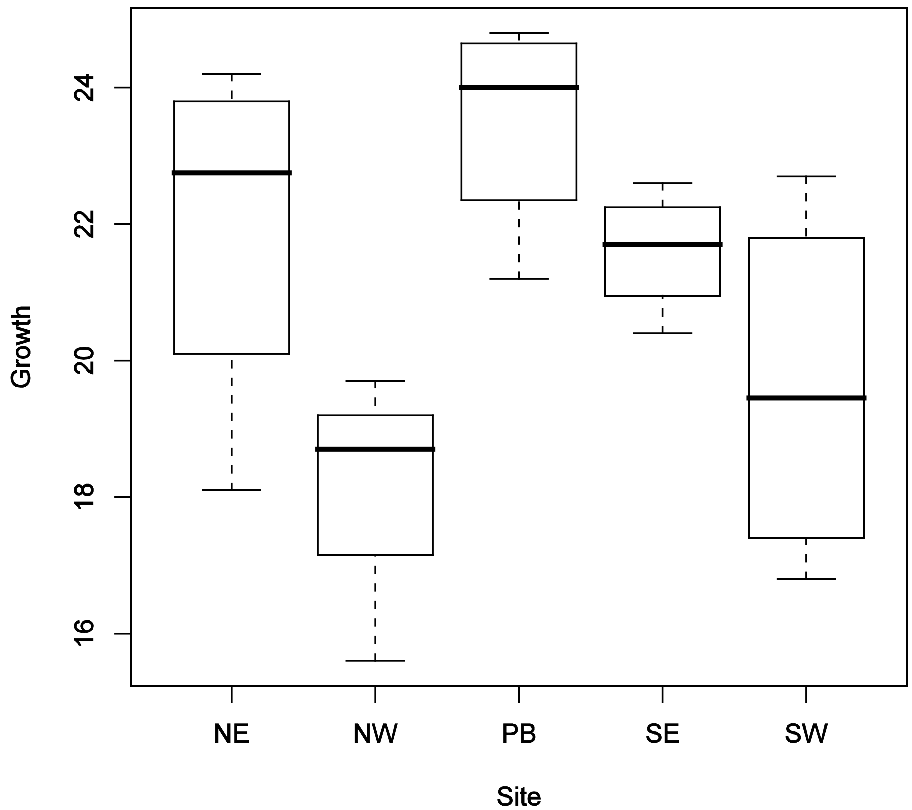
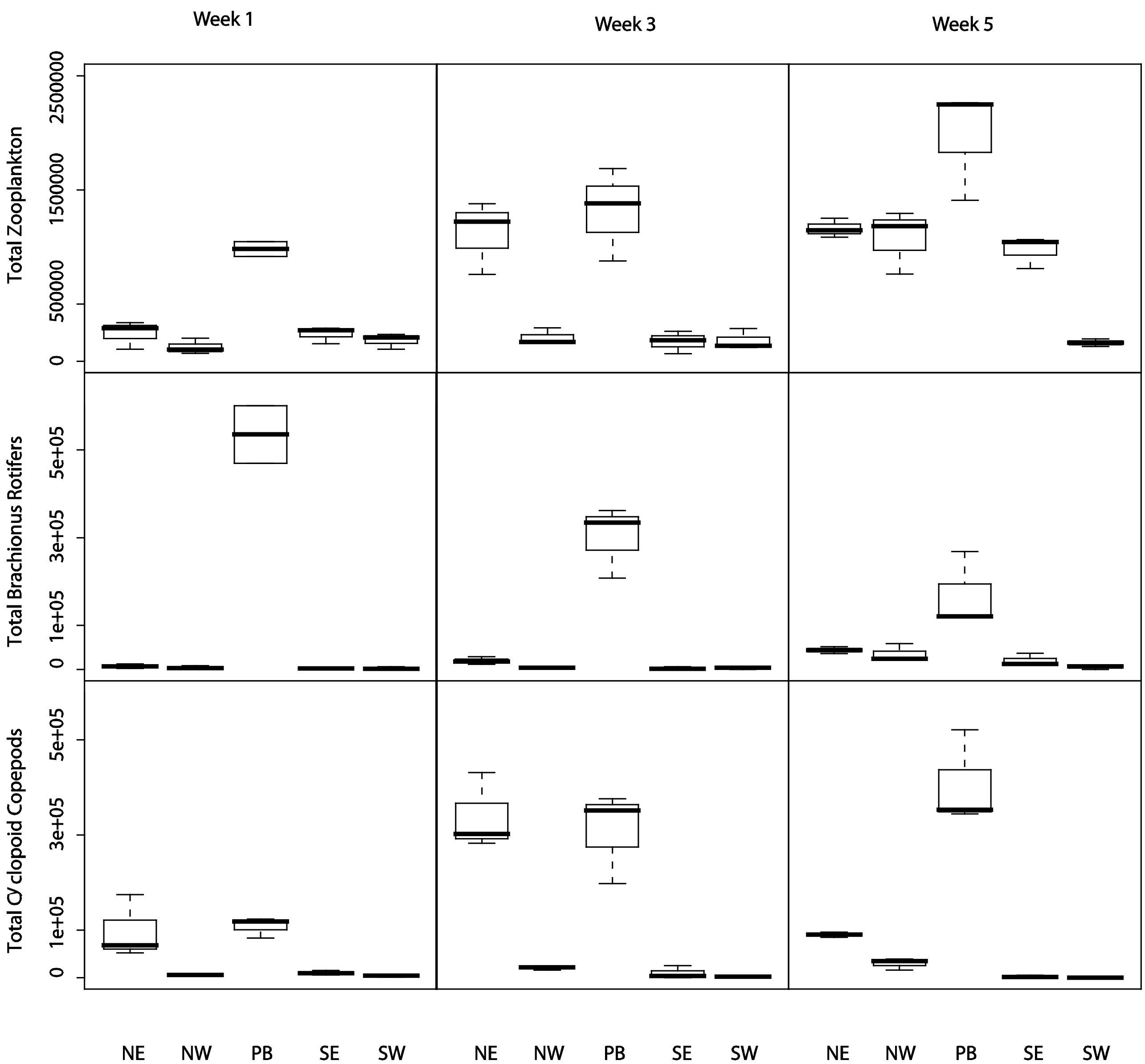
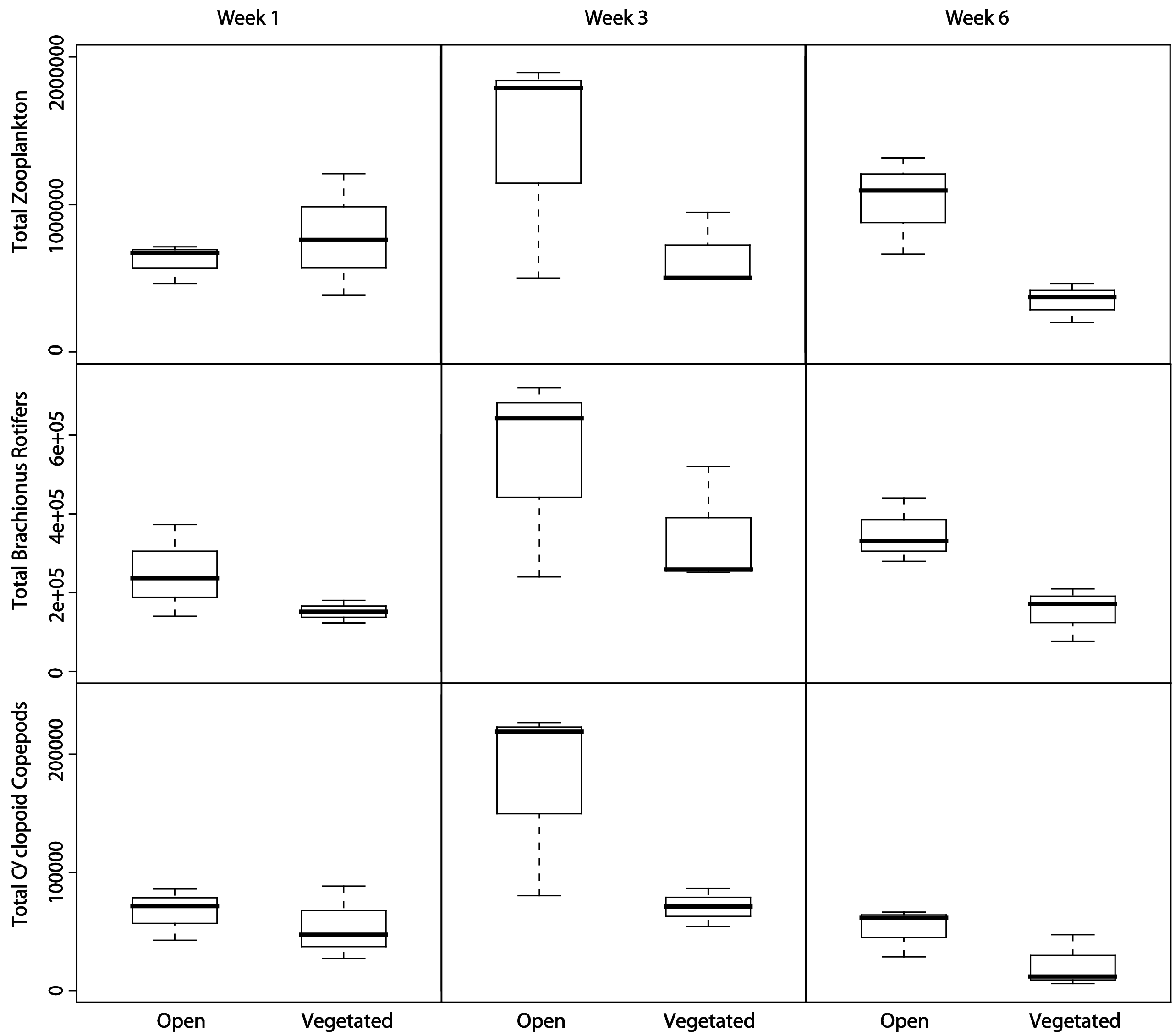


Figure 4.



Week 1
Week 3
Week 5
Total Zooplankton
0
500000
1500000
2500000
Total Brachionus Rotifers
0
1e+05
3e+05
5e+05
Total Cyclopoid Copepods
0
1e+05
3e+05
5e+05
NE
NW
PB
SE
SW
NE
NW
PB
SE
SW
NE
NW
PB
SE
SW

Figure 5.


Week 1
Week 3
Week 6
Total Zooplankton
0
1000000
2000000
Total Brachionus Rotifers
0
2e+05
4e+05
6e+05
Total Cyclopoid Copepods
0
100000
200000
Open
Vegetated
Open
Vegetated
Open
Vegetated

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